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COLLEGE OF ENGINEERING AND TECHNOLOGY

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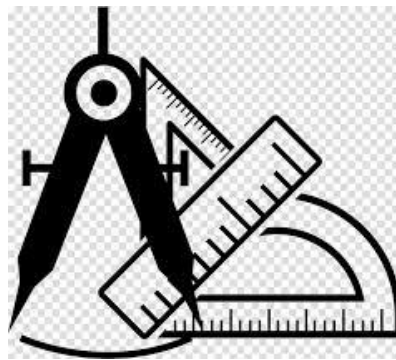
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DEPARTMENT OF MECHANICAL ENGINEERING

24ME403 - METROLOGY & MEASUREMENTS

Dr. A. ARUL MARCEL MOSHI,

ASSOCIATE PROFESSOR / MECH.



24ME403 - METROLOGY & MEASUREMENTS

UNIT III: TOLERANCE ANALYSIS

CO3: To apply the tolerance symbols & tolerance analysis for Industrial Applications

TOLERANCE STACK-UP

In mechanical engineering, no component can be manufactured to an exact nominal dimension due to inherent variations in manufacturing processes. Hence, tolerances are assigned to each dimension. When multiple components are assembled together, the individual tolerances combine or "stack up" to affect the final assembly dimension or clearance. This cumulative effect is known as tolerance stack-up. Understanding and analyzing tolerance stack-up is crucial for ensuring proper fit, function, and interchangeability of parts in an assembly.

Definition of Tolerance Stack-up:

Tolerance stack-up (also called tolerance accumulation) refers to the cumulative variation in an assembly dimension resulting from the combination of individual tolerances of the component parts. It determines the maximum and minimum possible gaps, interferences, or overall dimensions in an assembly. If not properly analyzed, tolerance stack-up can lead to assembly failures, excessive play, or interference between mating parts.

Types of Tolerance Stack-up analysis:

There are two main approaches to tolerance stack-up analysis:

- i) **Worst-Case Tolerance Analysis (Linear Stack-up):** Assumes that all individual tolerances occur at their extreme limits simultaneously. It guarantees 100% interchangeability but often results in very tight component tolerances.
- ii) **Statistical Tolerance Analysis (RSS Method - Root Sum Square):** Assumes that tolerances follow a normal distribution and are unlikely to occur at extremes simultaneously. It allows for looser component tolerances while still achieving acceptable assembly yields.

Simple Example of Tolerance Stack-up Problem:

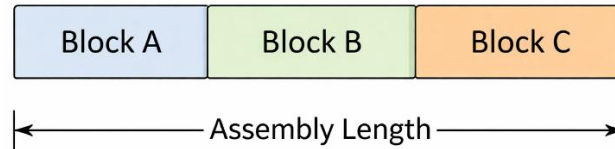
Consider a simple assembly consisting of three cylindrical blocks stacked together as shown below. The assembly must fit inside a housing of fixed length. The nominal lengths and tolerances of each block are given. Determine the overall length of the assembly and its variation.

Given:

Block A: Length = 20.00 mm \pm 0.10 mm

Block B: Length = 30.00 mm \pm 0.15 mm

Block C: Length = 25.00 mm \pm 0.12 mm



Solution using Worst-Case Tolerance Analysis:

Step 1: Calculate the nominal assembly length

$$\text{Nominal Length} = 20.00 + 30.00 + 25.00 = 75.00 \text{ mm}$$

Step 2: Calculate the maximum possible assembly length

For maximum length, all blocks must be at their maximum size.

$$\text{Max A} = 20.00 + 0.10 = 20.10 \text{ mm}$$

$$\text{Max B} = 30.00 + 0.15 = 30.15 \text{ mm}$$

$$\text{Max C} = 25.00 + 0.12 = 25.12 \text{ mm}$$

$$\text{Maximum assembly length} = 20.10 + 30.15 + 25.12 = 75.37 \text{ mm}$$

Step 3: Calculate the minimum possible assembly length

For minimum length, all blocks must be at their minimum size.

$$\text{Min A} = 20.00 - 0.10 = 19.90 \text{ mm}$$

$$\text{Min B} = 30.00 - 0.15 = 29.85 \text{ mm}$$

$$\text{Min C} = 25.00 - 0.12 = 24.88 \text{ mm}$$

$$\text{Minimum assembly length} = 19.90 + 29.85 + 24.88 = 74.63 \text{ mm}$$

Step 4: Calculate the Total Tolerance Stack-up:

$$\text{Total variation} = \text{Maximum} - \text{Minimum} = 75.37 - 74.63 = 0.74 \text{ mm}$$

(or) Total Tolerance = Sum of the individual tolerances = $0.10 + 0.15 + 0.12 = 0.74$ mm

Step 5: Final Result

Assembly Length = 75.00 mm ± 0.37 mm (or 74.63 mm to 75.37 mm)

Statistical Tolerance Analysis (RSS Method):

In statistical analysis, the total tolerance is calculated as the square root of the sum of squares of individual tolerances:

$$\text{Total Tolerance (RSS)} = \sqrt{[0.10^2 + 0.15^2 + 0.12^2]} = \sqrt{[0.01 + 0.0225 + 0.0144]} = \sqrt{0.0469} = 0.2166 \text{ mm.}$$

This gives an assembly tolerance of ± 0.2166 mm, which is tighter than the worst-case ± 0.37 mm. This method is used when high production volumes justify the statistical assumption and some percentage of assemblies may fall outside the limits.

Methods to minimize Tolerance Stack-up:

- Use selective assembly for critical fits.
- Use statistical process control to reduce manufacturing variation.
- Design with fewer components in the tolerance chain.
- Specify tighter tolerances only on critical dimensions.